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NSAM-67

U.S. NAVAL AIR TRAINING CENTER
NAVAL SCHOOL OF AVIATION MEDICINE
PENSACOLA, FLORIDA

RESEARCH REPORT

Submitted 25 July 1944

PROJECT NO:	X-402(Av-216-f)
REPORT NO:	One
TITLE:	Individual Variation in Respiratory Response to Carbon Dioxide at Altitude.
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SUMMARY:

1. The extent of increase in ventilation due to inhalation of carbon dioxide at 15,000 feet is approximately equal to that obtained at sea level when carbon dioxide tensions are the same under the two conditions.

2. Respiratory exchange at sea level while breathing 5 per cent carbon dioxide (36 mm. Hg. tension) was 2.25 times that while breathing air. At 15,000 feet, 9.25 per cent carbon dioxide (35 mm Hg. tension) was required to obtain the same change in ventilation.

3. Pronounced variability in response to carbon dioxide was noticed not only among different individuals but also in the same individual at different times both at sea level and at 15,000 feet simulated altitude.

4. At 15,000 feet the subjective indications of anoxia were relieved slightly, though definitely, by carbon dioxide tensions of 27 mm. Hg. or more in the inspired air.

CONCLUSIONS:

The respiratory response of a group of subjects to carbon dioxide was the same at 15,000 feet pressure altitude as at sea level when the same tension of carbon dioxide in the inspired air was used in both cases. Therefore, the respiratory response to carbon dioxide at this altitude is not altered by anoxia.

INTRODUCTION:

In accordance with BuMed directive X-402(AV-216-f), the respiratory response of a group of individuals to various amounts of carbon dioxide in the inspired air was studied. As stated in the directive, the study was to have included only a single concentration of carbon dioxide (5%) at sea level, and concentrations necessary to produce similar responses at various altitudes. It was considered that more informative results might be obtained if the study included several concentrations of CO_2 at sea level, and the concentrations required to produce similar responses at 15,000 feet. This modification of the directive was followed.

Although it is well known that CO_2 stimulates respiratory activity at sea level, very little quantitative data are available which show the magnitude of this response at altitude. With the current interest in the possible effects of CO_2 at altitude, it becomes of importance to determine this factor.

EXPERIMENTAL METHODS:

The gas mixtures were prepared in a Tissot Spirometer and transferred to a rubberized fabric gas container of approximately 800 liters capacity. Oxygen was added in amounts sufficient to restore the concentrations to approximately normal. Concentrations of CO_2, O_2 and N_2 were determined by means of the Haldane-Henderson apparatus for the analysis of respiratory gases.

The respiratory requirements of the subjects were supplied through a system of tubes containing check valves so arranged that the expired air could be collected for measurement. In the experiments at sea level the samples of expired gases were collected in the spirometer and measured directly, while those obtained in the low pressure chamber at a simulated altitude of 15,000 feet were collected in a Douglas bag and measured at altitude by means of a gas meter.

All experiments were performed with the subjects in the sitting position. The routine procedure of the experiments was as follows: (1) a preliminary period of several minutes was allowed for the subject to become accustomed to the mouthpiece and noseclip, and for respiration to become adjusted to the changed conditions: (2) while breathing ambient air the expired gases were collected for a period of three minutes, and the volume

measured; (3) the subject was then allowed to breathe the gas mixture for a period of three minutes in order that respiratory exchange might become adjusted to the increased CO_2 content of the inspired gases; (4) while breathing the gas mixture, and after the initial adjustment period, the expired gases were collected during an additional period of three minutes, and the volume measured; (5) the subject was again allowed to breathe ambient air for three minutes before a final period of collection, also of three minutes duration. The average of the two volumes collected while breathing ambient air was obtained. The number of respirations was counted during each period of collection.

RESULTS:

In Table I are shown data obtained from these experiments. It will be noted that CO_2 content of the gas mixture is reported in terms of partial pressure. All subjects exhibited an increase in respiratory minute volume during exposure to the CO_2 mixture. This increase was directly related to CO_2 tension. At sea level the rate of ventilation was approximately 2.25 times normal while breathing a gas mixture containing 5% CO_2 (36 mm. Hg. tension), while at 15,000 feet a similar rate was produced by 9.25 % CO_2 (35 mm. Hg. tension). Considerable variation in the magnitude of the response was noted both among the several subjects and in the same subject at different times. Frequently the respiratory rate increased during exposure to CO_2, but not invariably.

The relationship between respiratory exchange and CO_2 tension is shown in Figure 1. It will be seen in this figure that equal CO_2 tensions produced equal degrees of respiratory stimulation (within the limits of individual variability) whether at sea level or at 15,000 feet.

At altitude (15,000 feet) all subjects noted definite indications of anoxia while breathing ambient air. More common among these were impairment of peripheral vision, physical weakness, and uneasiness or apprehension. While breathing CO_2 at tensions of 27 mm. Hg. or higher, all subjects noted a slight though definite improvement with respect to these indications of anoxia.

DISCUSSION:

Pulmonary ventilation is increased by the addition of CO_2 to the inspired gas mixture, and the extent of this increase at a simulated altitude of 15,000 feet

is approximately equal to that observed at sea level when CO_2 tensions under the two conditions are equal. From this it is evident that the degree of anoxia which exists at this altitude does not alter, to a significant extent, the response of the respiratory mechanism to CO_2. The physical work involved in ventilation at a rate two or more times the normal is definitely annoying at sea level, though not extremely so. At altitude the annoyance is reduced, probably because of the greater ease with which adequate quantities of the less dense gases can be drawn into the lungs. Whether or not the extent of the amelioration of the subjective symptoms of anoxia obtained from such a rate of ventilation is sufficient to justify the means of its accomplishment has not been demonstrated. Further, it is reasonable to suppose that a respiratory system which is already in a state of stimulation will be less able to readjust itself to meet additional demands should the occasion arise. Also the great variability in the responses of different individuals (or even the same individual at different times) to a given concentration of CO_2 should be noted.

TABLE I

Respiratory Exchange at Sea Level and at Altitude While Breathing Air and CO_2 Mixtures.

Subj. No.	Altitude	CO_2 mmHg	Minute Volume Liters per min. Air	Minute Volume Liters per min. CO_2	CO_2 / Air	Respiration rate Air	Respiration rate CO_2	CO_2 / Air
1	S.L.	16.5	8.1	9.8	1.21	13	12	.92
	15,000	19.2	7.6	10.2	1.34	10	12	1.20
	S.L.	23.6	7.6	13.1	1.72	12	14	1.17
	15,000	27.6	8.0	18.4	2.30	11	13	1.18
	15,000	33.6	7.1	17.1	2.41	13	16	1.23
	S.L.	35.6	8.4	12.5	1.49	12	12	1.00
	S.L.	36.2	6.9	16.8	2.44	11	13	1.18
2	S.L.	16.5	8.2	10.3	1.26	9	10	1.11
	15,000	19.2	7.5	11.3	1.51	7	9	1.29
	S.L.	23.6	7.4	11.5	1.55	8	9	1.13
	15,000	27.6	8.4	16.6	1.98	8	12	1.50
	S.L.	30.2	7.7	12.9	1.68	9	11	1.22
	15,000	33.6	7.6	17.4	2.29	9	12	1.33
	S.L.	35.6	7.6	16.0	2.10	8	14	1.75
	S.L.	37.0	7.8	20.3	2.60	8	12	1.50
3	15,000	17.2	9.0	14.4	1.60	11	13	1.18
	S.L.	23.6	8.9	15.3	1.72	8	9	1.13
	S.L.	28.8	9.7	13.8	1.42	9	9	1.00
	15,000	33.6	9.7	17.1	1.76	9	9	1.00
	15,000	35.2	8.8	20.8	2.36	10	11	1.10
	S.L.	36.2	9.6	18.1	1.89	11	11	1.00
4	S.L.	20.8	7.4	11.7	1.58	10	12	1.20
	15,000	29.4	8.2	15.2	1.85	10	13	1.30
	S.L.	35.8	7.1	15.9	2.24	10	14	1.40
5	15,000	29.4	10.5	19.2	1.83	12	14	1.17
	S.L.	35.8	8.6	25.0	2.91	10	14	1.40
6	15,000	17.2	10.5	13.3	1.27	17	17	1.00
	15,000	32.0	11.3	17.0	1.50	17	18	1.06
	S.L.	36.2	8.4	20.0	2.38	13	16	1.23
7	S.L.	37.0	11.6	26.3	2.27	15	18	1.20
8	S.L.	20.8	11.1	13.4	1.21	21	21	1.00
9	S.L.	20.8	11.9	18.3	1.54	22	25	1.14
10	S.L.	20.8	10.4	14.2	1.36	22	22	1.00
11	S.L.	20.8	10.8	14.9	1.38	16	16	1.00
12	15,000	32.0	8.3	15.9	1.92	11	14	1.27
	15,000	35.2	9.0	19.1	2.12	12	15	1.25
13	S.L.	28.8	8.1	14.6	1.80	15	19	1.27
	15,000	35.2	8.0	19.4	2.42	15	21	1.40
14	S.L.	28.8	9.9	17.1	1.73	15	17	1.13
15	S.L.	28.8	10.6	14.3	1.35	14	15	1.07

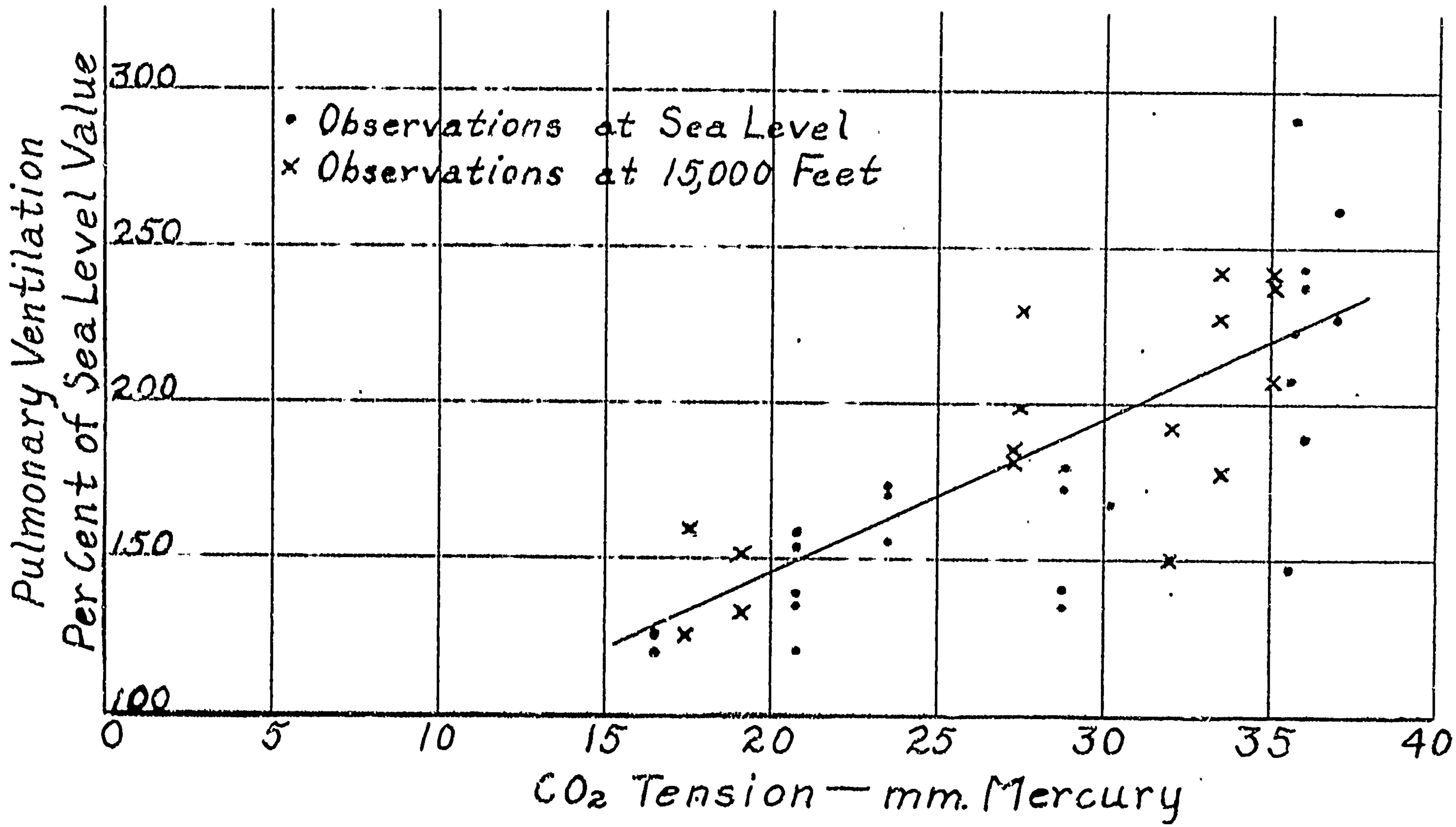
Pulmonary Ventilation
Per Cent of Sea Level Value
300
250
200
150
100
• Observations at Sea Level
× Observations at 15,000 Feet
0
5
10
15
20
25
30
35
40
CO_2 Tension — mm. Mercury

Figure 1.